IN USE: ADVANCE WELDING PROCESS DEVELOPMENT IN THE NUCLEAR POWER INDUSTRY

ISSUE STATEMENT

Construction and maintenance of nuclear power plants has been predominately performed with shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW). While serviceable, these technologies have some fundamental limitations that cannot be overcome through process optimization.

SMAW and GTAW production rates are inherently limited by travel speed and delivery of filler material to the weld puddle. Currently, GTAW and SMAW butt welds require the use of groove preparation and numerous weld passes to fabricate nuclear components. Advanced welding technologies could yield significant production benefits by producing butt welds with no groove preparation and, in most cases, using a single pass of welding.

SMAW and GTAW technologies are limited in their ability to address mitigation needs of operating plants, including application of Alloy 52 weld overlays and repairs to highly irradiated reactor internals. GTAW is a moderate to high heat input process that causes difficulty relative to controlling dilution of the overlay material by the substrate material. As a result, little margin exists and the welding procedure and filler metals must be carefully controlled in order to obtain acceptable results. For many irradiated reactor internals, conventional welding processes cannot be applied as a repair technique. Highly irradiated material has a propensity to crack when welded with processes where melting of the material occurs.

Finally, SMAW and GTAW are limited in their ability to produce low residual stress weld joints in various configurations. When fabricating replacement components and components for new plants, it is highly desirable that some components have low weld residual stress. Application of welding processes that eliminate weld residual tensile stresses would produce components resistant to stress corrosion cracking, without any need for application of post-weld mitigation.

DRIVERS

Operational Impacts

Light water reactor designs include key structural components that may require repair or degradation mitigation to support reactor life extension. If the structural integrity of these components is compromised by degradation, reactor operability could be challenged. During new plant construction, welds made with low levels of residual stress have a lower propensity for degradation and therefore a higher probability of achieving extended service lives. In addition, advanced processes have the potential to minimize the weld volume and interactions with the base material, improving the inspectability and reducing the potential of weld defects.

Cost

Replacement of reactor components and internals is a costly undertaking involving not only the removal and replacement of the components, but also cut-up and disposal of the replaced radioactive components. Welded repair may be a cost effective alternative to replacement. Long-term costs associated with welded repairs and replacement are ultimately reduced with improvements in inspectability, weld quality and productivity, and the reduction of welding distortion and residual stresses.

Regulatory

MRP-139 has specified a schedule for the mitigation of locations in the PWR reactor design that apply to materials susceptible to primary water stress corrosion cracking. Use of advance welding processes could be one solution to the Alloy 52 weldability issue that affects the application of mitigation processes.

RESULTS IMPLEMENTATION

Research results would be made available to nuclear steam supply system vendors and repair organizations that provide mitigation activities to the current light water reactor fleet. Results will include suggested equipment configurations, results from screening tests on materials used to construct light water reactors, and application parameters for each material type tested. ASME code cases and associated technical bases would support the application of these advanced welding processes to nuclear power plant components.

PROJECT PLAN

R&D will be coordinated with other industry stakeholders.

Throughout the program, EPRI will select appropriate organizations to collaborate with, including U.S. national laboratories, welding equipment manufacturers, nuclear steam supply system vendors, and other welding specific research organizations (e.g., Edison Welding Institute, The Welding Institute, universities). The R&D approach will be integrated with ongoing work related to irradiated materials welding (described in the Irradiated Materials Welding Roadmap) and other work related to all aspects of plant maintenance and new plant construction.

Advanced welding technologies offer many potential advantages, including higher production, reduced interaction with the base material, reduced potential for weld defects, improved welding residual stress profile, and enhanced inspectability. High-energy density processes such as hybrid welding and laser beam welding (LBW) represent a potential solution, since these processes are capable of producing welds with very low levels of base metal interaction providing a larger margin to dilution-related cracking and improved weld residual stress profile.

This work is divided into short-range and long-range activities. The short-range activities focus on development and application of a uniform assessment method for the suitability of each advanced welding process to light water reactor maintenance and construction. Where advanced welding processes are determined to be suitable, long-range research activities are focused on bringing these technologies into a production-ready state.

Short-range activities include

- Develop detailed uniform assessment methodology for evaluating each advanced welding process for use in the light water reactor industry
- Select the most qualified provider/vendor for testing of each advanced welding process
- Develop laser and hybrid welding predictive models for welding irradiated stainless steel and typical plant components
- Develop techniques for applying laser/hybrid welding to reactor internal repairs and new construction
- Refine BWR weldability assessment

Long-range activities include:

- Perform a test plan on weld joints and material that are typical to light water reactor components
- Perform study on the modification to the process and equipment that would be needed for application in the light water industry
- Compile a report documenting the finding from each evaluation of each advanced welding technology
- Implement ASME code cases as needed for the implementation of each advanced welding technology

Although advanced welding processes are applied in other industries, implementation barriers currently limit their application in the nuclear industry. A majority of the fundamental technology development for these advanced welding processes has been performed in the aerospace and aviation industries. Validation of these processes on nuclear industry materials is needed. Subsequently, these processes must be adapted to the weld configurations of interest, such as piping, cladding and vessels. Finally, for maintenance of the existing nuclear power plant fleet, these advanced welding processes must be adapted for field deployment before they can be applied as proven technologies.

RISKS

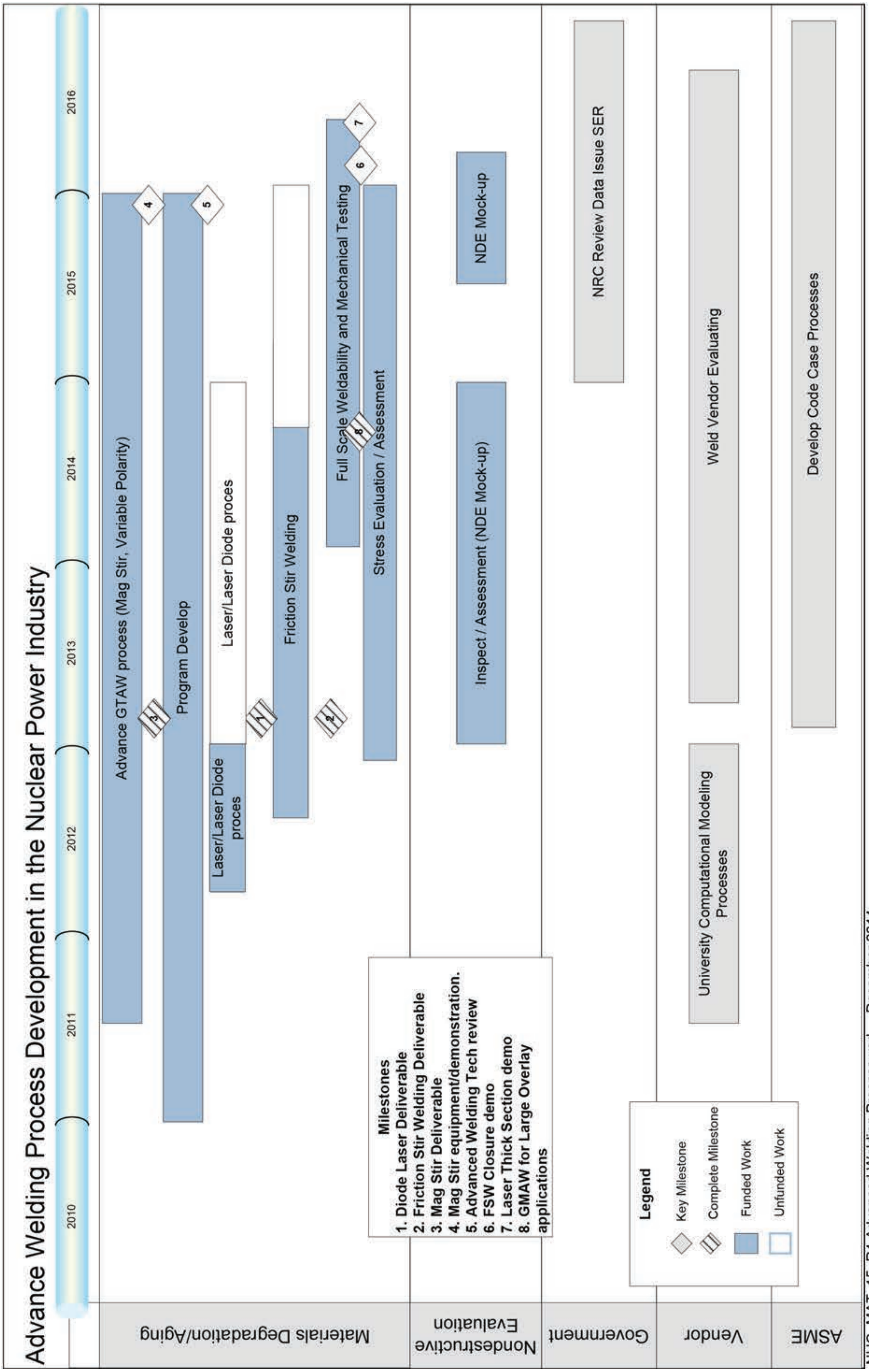
Some advanced welding processes require code and regulatory approval prior to application to reactor components. Additionally, friction stir welding is not currently addressed by ASME code and thus code modification will be required before implementation can occur. In both of these cases, review schedules and outcomes can be uncertain and difficult to predict.

Development of field-ready advanced welding processes is a significant cost investment and the project plan includes coordinated efforts with other organizations. Even if the EPRI-owned tasks are funded, there is no guarantee that other organizations will have the expected funding available.

RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

Revision	Description Of Change
0	**Original Issue:** August 2011 **Roadmap Owner:** Greg Frederick
1	**Revision Issued:** August 2012 **Roadmap Owner:** Greg Frederick **Changes:** Updates to flowchart include: Added Stress Evaluation/Assessment from start of 2013 to end of 2015. Changed Interim NDE Mock-up to Inspect/ Assessment. Added milestones for topical reports.
2	**Revision Issued:** August 2013 **Roadmap Owner:** Greg Frederick **Changes:** Updated flow chart.
3	**Revision Issued:** January 2014 **Roadmap Owner:** Greg Frederick **Changes:** Added milestones legend and 3 milestones completed.
4	**Revision Issued:** December 2014 **Roadmap Owner:** Greg Frederick **Changes:** Added milestones 4-8. Milestone 8 completed. Extended Advance GTAW process, program develop and Develop Code Case processes to the end of 2015.



Advance Welding Process Development in the Nuclear Power Industry
2010
2011
2012
2013
2014
2015
2016
Materials Degradation/Aging
Advance GTAW process (Mag Stir, Variable Polarity)
Program Develop
Laser/Laser Diode proces
Laser/Laser Diode proces
Friction Stir Welding
Full Scale Weldability and Mechanical Testing
Stress Evaluation / Assessment
Nondestructive Evaluation
Inspect / Assessment (NDE Mock-up)
NDE Mock-up
Government
NRC Review Data Issue SER
Vendor
University Computational Modeling Processes
Weld Vendor Evaluating
ASME
Develop Code Case Processes
Milestones
1. Diode Laser Deliverable
2. Friction Stir Welding Deliverable
3. Mag Stir Deliverable
4. Mag Stir equipment/demonstration.
5. Advanced Welding Tech review
6. FSW Closure demo
7. Laser Thick Section demo
8. GMAW for Large Overlay applications
Legend
Key Milestone
Complete Milestone
Funded Work
Unfunded Work
NUC_MAT_15_R4 Advanced Welding Process.vsd December 2014